

INVESTIGATION TO IMPROVE THE NEW PRODUCT DEVELOPMENT PROCESS OF MONO BLOCK PUMP USING ADDITIVE MANUFACTURING

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ABSTRACT

In today's global competitive manufacturing, industries are seeking for new ideas to produce products at cheaper price, better quality and deliver quickly. A product may consist of several components. Currently, manufacturers adopt several approaches to produce a product but widely used approaches are Conventional manufacturing and CAD/CAM approach. In the first approach, each component is machined in conventional machine tools and they are assembled together to produce a product. In the second approach, each component is designed and developed using CAD/CAM systems and they are machined using CNC machine tools. These components are then assembled together to form the final product. In our investigation, Additive manufacturing (AM) is used where the final assembled product is produced in a single machining process and there is no assembly operations required. In the first two approaches, the final product is made by removing materials, whereas, in AM, the final product is made by adding materials layer by layer. AM is also known as 3-D printing or Rapid prototyping. In India, mono block pump product is manufactured using conventional machining. In some industry, CAD/CAM approach is used. The cost of this product is high and farmers find it difficult to afford it. In addition, quality of the product is not up to industry benchmark. In this paper, an investigation is carried to determine whether AM can be used as an alternative solution to produce pumps. With this, an attempt is made to improve the quality of the pump and the product development process. From the investigation, the result conclude that additive manufacturing can be used to manufacture pumps with better quality and reduced product development time; however there are restrictions in material constraint.

KEYWORDS: Conventional Manufacturing, CAD/CAM System, Additive Manufacturing, 3D Printing, Rapid Prototyping, Reverse Engineering, Product Development cycle

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1. INTRODUCTION

India has a population of 1.2 billion and agriculture plays a vital role in the economy. Pumps are used as equipment for irrigation purpose and farmers widely depend on it. In other words, there is a huge demand in pump industry. The cost of the mono block pumps depends on water discharge and they are mostly dictated by pump manufacturers. In addition, some of the pumps do not meet the industry average quality level; however the pump industries survive due to less competition.

In Today's scenario, huge investment is required to start a new pump industry. This is because of current manufacturing processes, which involves from foundry to machining centers. The current manufacturing processes

to produce pumps are conventional manufacturing and CAD/CAM approach. In these processes, the materials are removed from the parent

Components using either conventional machine tools or CNC machine tools. To operate these machine tools, high skill operators are required. Currently, India is facing scarcity in skilled labors. For this reason, manufacturers find difficulty in identifying qualified skilled labor or need to pay high wages to sustain skilled labors. Due to this, they cannot place their product at competitive price in the global competitive environment. On the other hand, some pump manufacturers use the existing workforce (who has less skills to operate the machines) to manufacture pumps where the quality of the product is compromised. In this case, the end customer (farmers) suffer the most. Therefore, manufacturers seek for new ideas to produce the pump at cheaper price, able to meet or beat the competitor's product quality and able to deliver the product quickly to the customers by reducing product development process.

In this paper, an investigation is carried out to study: (a) the current manufacturing processes of a pump and propose alternative solutions to improve the quality; (b) new ideas or methods to manufacture the pump at cheaper rate, and faster (improved product development process).

2. LITERATURE REVIEW

Now-a-days, most of the end-products are manufactured using either conventional manufacturing process or CAD/CAM approach. The idea to use AM technology to produce end-products are still in research stage. Ganesh et. al [1] demonstrated CAD/CAM approach to improve the quality of pump discharge and reduction in product development time. They also pointed out that still many pump industries still use conventional machine tools to manufacture pumps. Erika et al. [2] provided a procedure to manufacture a threaded component with minimum tool position with the help of integration of CAM software in 5-axes CNC machine. Hoque et al. [3] proposed a library to integrate the design and manufacturing phases of CAD/CAM system to reduce the product cost. Gomez et.al. [4] proposed a methodology to produce wind turbine blades using CAD/CAM approach to ensure perfect aerodynamics. Stephen et al. [5] proposed a basic framework to implement Additive manufacturing. Donghong et al. [6] formulated a methodology to generate path planning for Additive manufacturing of thin walled materials to increase the material efficiency. Peng et al. [7] provided a solution to address the issues related to the limitation of work volume in Additive manufacturing process. Ben et al. [8] optimized the support structure work volume by altering the orientation of the component in Additive manufacturing process. Wei et al. [9] discussed the advantages, limitations and the challenges of Additive manufacturing process in perspective of manufacturers. A part consolidation method to optimize the design, reduce the part count and achieve ease of assembly using Additive manufacturing process was discussed by Sheng et al. [10].

Metelnick [11] quoted that designers in 1970's take three times more in manufacturing parts than using today's technology (rapid prototyping). Kochan and Chua [12] provided rapid prototyping limitations in the product development process. Ulrich et al. [13] pointed out that time is the major factor influence the product development and methods and advanced technology plays a major role towards it. Lee [14] added material selection is one more factor influence a product development in rapid prototyping. Basrour et al. [15] defined 3D micro objects to develop complex components using MSL. Toyoto [16] uses Additive manufacturing in their product development process, to be specific design and testing of their automobile components.

The CAD drawing is imported into Additive manufacturing machine in the format of STL. Donahue [17] pointed out two format of STL file: ASCII and binary. The ASCII file is size is larger than binary format but ASCII file is readable and it is imported to any additive manufacturing machines.

Several researchers [1-4] compared the CAD/CAM/CNC approach with the conventional manufacturing process. Whereas, researchers [4,9-10] compared the conventional manufacturing with AM. Researchers [6-8] discussed the limitation of improvement methods of AM process. Thus, limited literatures are found on comparison of all three approaches. In addition, no literature was found on the case study of developing mono block pump using all three approaches.

3. METHODOLOGY

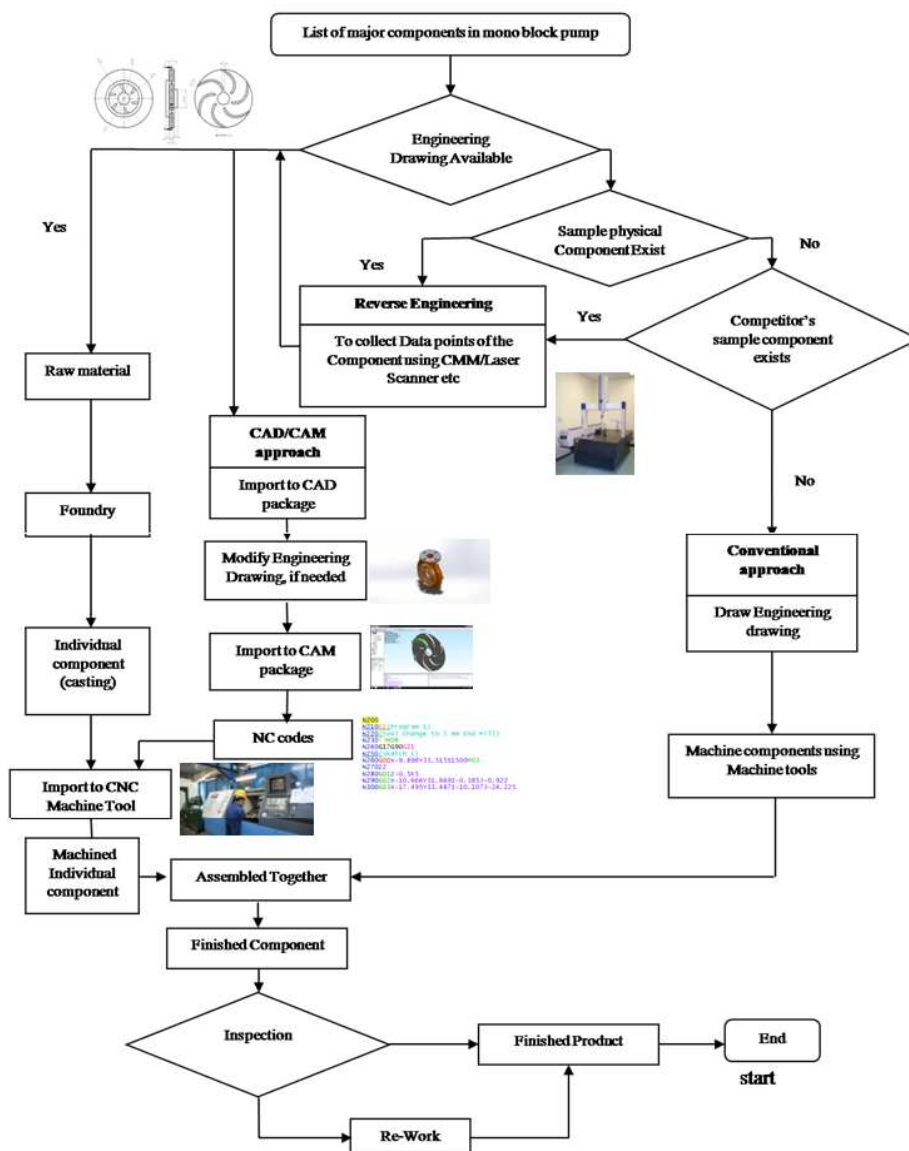


Figure 1: Methodology to Manufacture Mono Block Pump Using Conventional and CAD/CAM Approaches

In this section, a general methodology to manufacture a mono-block pump product using conventional manufacturing and CAD/CAM approach with the concept of reverse engineering is discussed. Figure 1 shows that methodology to manufacture a mono-block pump using these traditional approaches.

The main body of the mono block pump is cast iron material. Therefore, most of the components are casted in the foundry based on the engineering drawings. When the engineering drawing of any component is not available, then the concept of reverse engineering is used. The details of it will be discussed in the coming section.

The engineering drawing of each component is drafted in Computer-aided Design (CAD) package, mostly 2-D models. The operator machine the components using conventional machine tools or CNC machine tools. With CNC machine tools, numerical control (NC) codes are entered manually in the Human Machine Interface (HMI) of the machine. In both the cases, the quality of the machining is based on the operator skills. In addition, the product development time is directly proportion to operator skills. This process is called conventional machining of mono block pump. Figure 2 shows the flow chart of the manufacturing processes of mono block pump using conventional machining.

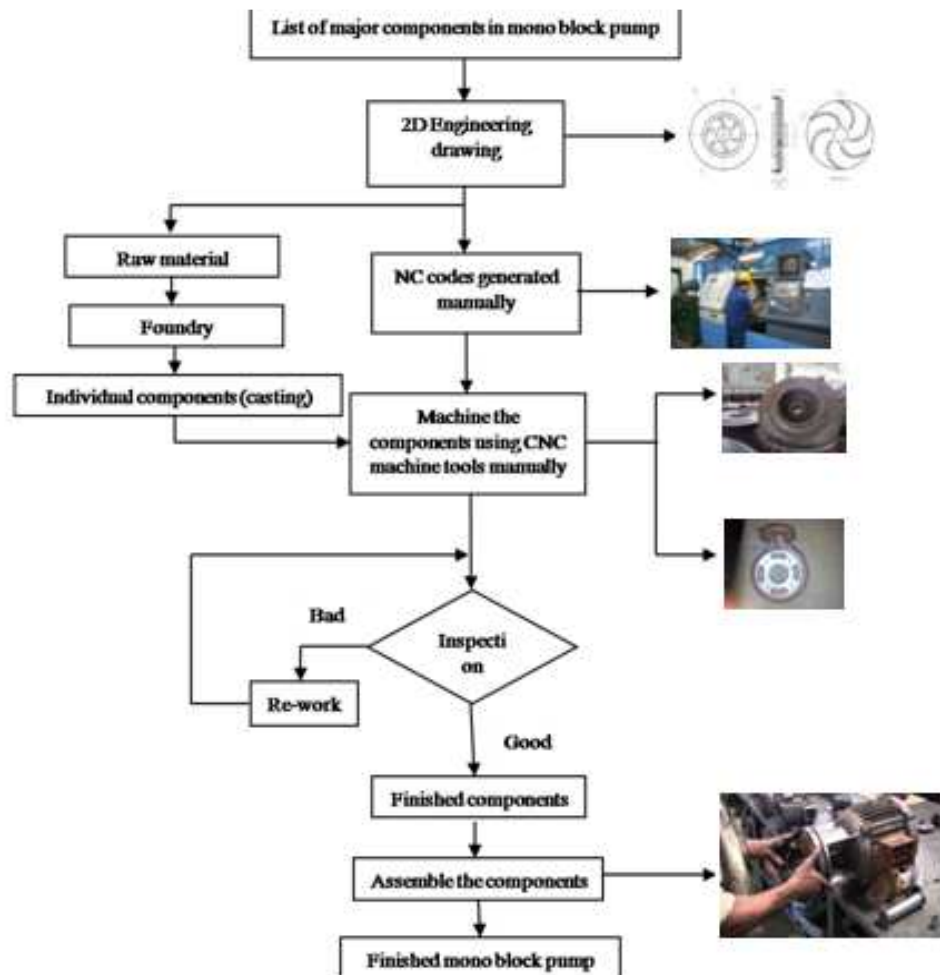


Figure 2: Flow Chart of Conventional Manufacturing Process of a Mono Block Pump

The CAD/CAM approach follow the same process except the generation of NC codes and its integration to CNC machine tools. In this process, conventional machine tools are not used. The engineering drawing of each component is

drafted in CAD package, mostly 3-D models. Then, each model is transferred into Computer-aided Manufacturing (CAM) software package. This package helps to generate optimum NC codes based on the machine tool parameters such as tool, coolant, cutting parameters, etc. The generated NC code can be directly integrated into CNC machine tools from CAM package or NC code can be saved to a storage device, which can be integrated manually. In this approach, the quality of machining is based on the operator skills. With this process, the product development time is reduced because the optimum NC codes are generated by the software. Figure 3 shows the flow chart of manufacturing of Mono block pump using CAD/CAM approach.

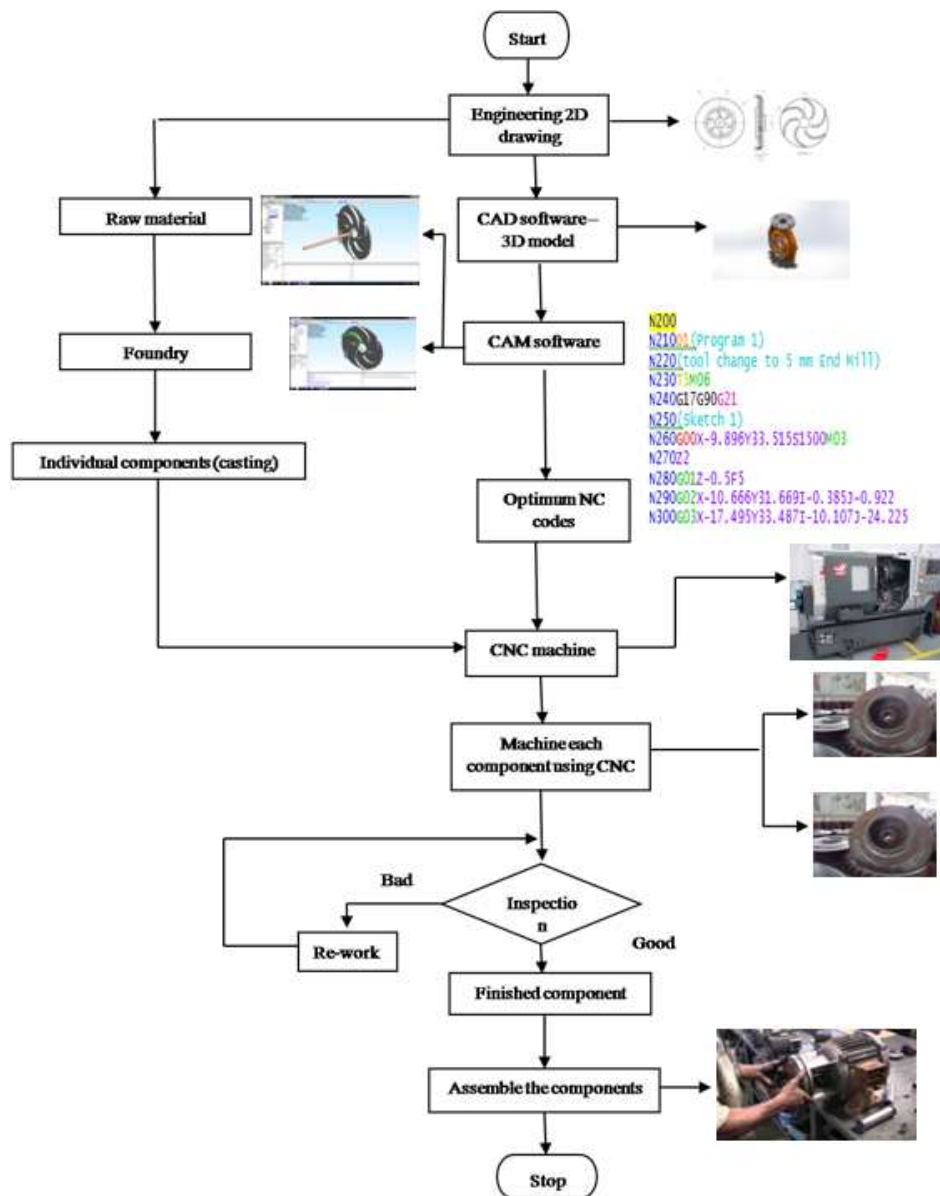


Figure 3: Flow Chart of CAD/CAM Approach for a Mono Block Pump

Reverse Engineering

Reverse engineering is the process of extracting design information from the existing product to reproduce it. In traditional manufacturing processes, the operator measure the existing product dimensions using vernier caliper to collect

the data point. These data points are used to generate the engineering drawing (2-D or 3-D models).

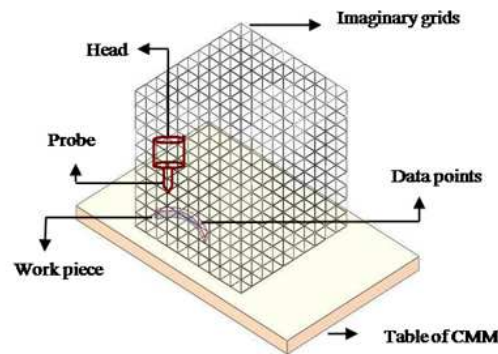


Figure 4: CMM Workspace with Imaginary 3D Grids and Data Points

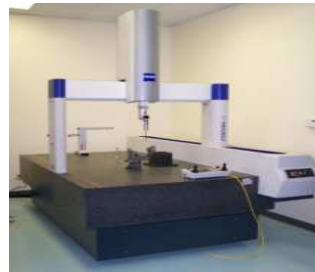


Figure 5: Zeiss Contura G2 (Bridge Type CMM)

Table 1: Specification of Zeiss Contura G2 CMM Machine

Measuring Range- XYZ (mm)	1000 x 1200 x 600
Work piece weight (Kg)	1150 (max.)
Machine weight (Kg)	2301
Dimensions (WxDxH)	1734x2030x2800 mm
Linear error (μm)	$1.8+L/300$
Probing error (μm)	1.8
Scanning error (μm)	3.5
Form error (μm)	1.8
2D Probing uncertainty (μm)	10
1D Autofocus uncertainty (μm)	50

The Coordinate Measuring Machine (CMM) is used to measure the data points of the component. The CMM is used to collect high accuracy data point. For this, a 3D imaginary grid is formed representing x, y and z coordinates of workspace, as shown in Figure 4. A probe, mostly made of ruby, act as a sensor, which is mounted on the head of the CMM machine. When this probe touch the component, data point (x, y, z) of that location is collected via HMI. Figure 5 shows Zeiss Contura G2 CMM machine, used to collect the data points of the components where engineering drawings are not available. Table 1 shows the Zeiss Contura G2 CMM machine specification.

4. CASE STUDY

The case study pump manufacturer portfolio includes mono block pump, submersible pump, etc. In this, mono block pumps are sold in large number. Several customers have backlogs of two months to receive their pump. However, in recent times, several customers complaint about poor water discharge and water leakage problems. The industry is facing

labor scarcity locally. Having this in mind, an investigation was conducted to identify alternative solutions to improve the quality of the pump and reduce the product development process.

The mono block pump consists of several components such as casing, impeller, shaft, bracket, seals and motor put together to form a pump. Some of the components such as casing, impeller and bracket are manufactured in-house and other is purchased from vendors. Figure 6 shows a sample mono block pump.



Figure 6: Sample Mono Block Pump

5. EXPERIMENTAL SET-UP

The in-house components of mono block pump are manufactured using traditional approaches (conventional machining and CAD/CAM approach). In this process, time study, motion study and detailed manufacturing processes are observed. With this, the new approach - additive manufacturing process is also investigated.

5.1 Additive Manufacturing

Currently, there are four types of additive manufacturing process available: (a) Extrusion Deposition, (b) Binding of Granular materials (c) Lamination (d) Photo Polymerization.

In extrusion deposition, a plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. There is typically a worm-drive that pushes the filament into the nozzle at a controlled rate. The nozzle is heated to melt the material. Then the thermoplastics are heated past their glass transition temperature and they are deposited by an extrusion head [18].

The binding of granular material is the selective fusing of materials in a granular bed. The technique fuses parts of the layer and then moves downward in the working area, adding another layer of granules and repeating the process until the piece has built up. This process uses the unfused media to support overhangs and thin walls in the part being produced, which reduces the need for temporary auxiliary supports for the piece. A laser is typically used to sinter the media into a solid [18].

In lamination process, layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter. The objects printed with this technique may be additionally modified by machining or drilling after printing. Typical layer resolution for this process is defined by the material feedstock and usually ranges in thickness from one to a few sheets of copy paper [18].

Photopolymerization is also a 3-D printing process whereby drops of a liquid plastic are exposed to a laser beam of ultraviolet light. During this exposure, the light converts the liquid into a solid. The term comes from the roots photo,

meaning light, and polymer, which describes the chemical composition of the solid plastic [18].

With these four types, there are several techniques to produce products. Some of these techniques are: (a) Stereolithography; (b) Selective Laser Sintering; and (c) Fused Deposition Modeling.

The stereolithography technique uses photo polymerization. In Stereolithography, a concentrated beam of Ultra Violet (UV) rays are used to solidify a liquid polymer by tracing a 2D layer. After the solidification of first layer, the build platform is lowered and another layer of liquid polymer is brought to the top. The process is continued till the completion of the final product. The popular stereolithography machine used in India is System Viper Si2. The selective laser sintering technique uses binding of granular materials and Sinterstation (2500+) machine is widely used AM machine in India. The working principle of Selective laser sintering is similar to stereolithography but, the granular materials are heated by laser beam to melt and joined to form the solid product. The third technique is fused deposition modeling. This uses extrusion deposition of materials. In Fused Deposition Modeling, the material is heated just above its melting point and it is extruded from a nozzle which moves in such a way to deposit the material layer by layer in the desired shape based on the 3D model imported to the machine. The most popular machine used in India is Stratasys FORTUS 900 mc (see Figure 7).



Figure 7: Stratasys FORTUS 900mc (Fused Deposition Modelling Machine)

Figure 8 shows the working principle of a typical additive manufacturing process. In this, the completed 3-D assembled product (in our case, mono block pump) is designed in Solid Works 2012 software. A small clearance of water dissolvable material is added between stationary component (example: casting, impeller, etc.) and rotating component (example: shaft, impeller, etc.). This is because, when the material is added together, this small dissolvable material acts as a supporting element, which can be removed later by using water. Thus, the rotating components function later. The complete 3-D assembled model is then converted into STL file format, where the model is in tessellated form (splitting the model into small triangles). The size of the triangle determines the accuracy of the final product quality. The STL file is imported into the AM machine. The AM machine used in this case study is Stratasys FORTUS 900mc machine. The specification of the Stratasys FORTUS 900mc is illustrated in Table 2. The material used for AM is ABS-M30i with water soluble support structure (SR30). The properties of ABS-M30i (Ivory color) is shown in Table 3.

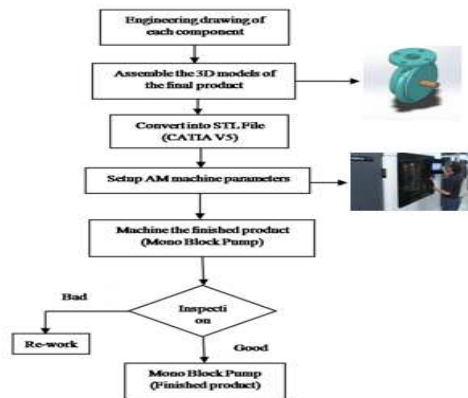


Figure 8: Flow Chart of Additive Manufacturing Approach for Mono Block Pump

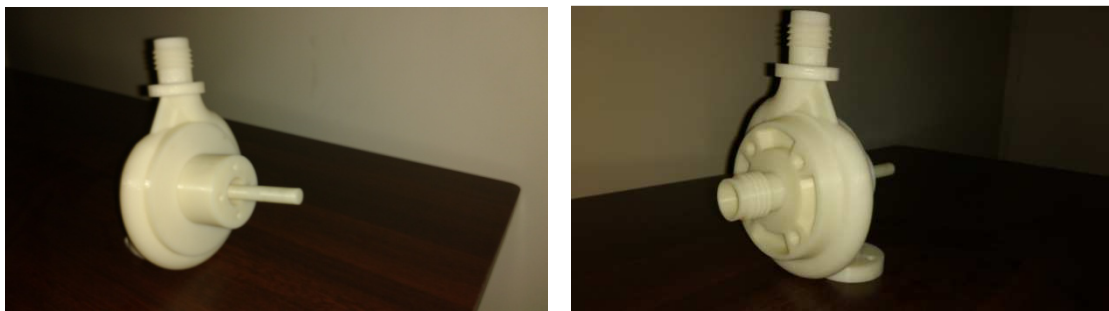


Figure 9: Mono Block Pump Manufactured in Additive Manufacturing

Table 2: Specification of Stratasys FORTUS 900mc

Machine Name	Stratasys FORTUS 900mc
Material	ABS-M30i (Ivory color)
Build size	914 x 610 x 914 mm (36 x 24 x 36 in.)
Layer thicknesses	0.254 mm (0.01 in.)
Support structure	Water Soluble support material
System size/weight	2772 x 1683 x 2027 mm (109.1 x 66.3 x 79.8 in.)/with crate: 3287 kg (7247 lbs.), without crate: 2869 kg (6325 lbs.)
Achievable accuracy	±.09 mm
Workstation compatibility	Windows 2003 through Windows 8
Network communication	10/100 base T connections; Ethernet protocol
Power requirements	230VAC nominal three-phase service with 5% regulation; 230VAC as measured phase-to-phase; 50Hz or 60Hz; 40 Amp circuit.

Table 3: Properties of ABS-M30i

Properties	Metric
Tensile strength	36 MPa
Tensile elongation	4 %
Flexural strength	61 MPa
IZOD impact, notched	139 J/m
Heat deflection	96 °C
Coefficient of thermal expansion	8.82E-05 mm/mm/°C

The AM machine set-up is carried out based on the work piece material, orientation of the component, support material etc. The operator could modify the machine set-up based on the functional surfaces, cost, surface finish required and the complexity of design. The orientation of the product is fixed in horizontal to reduce the manufacturing cost. The ABS-M30i is heated to molten state and the two dimensional layer is traced using a nozzle. By tracing successive layers as per the 3D model, the required product is built. In AM approach, the complete product can be built in one-piece. There is no or little assembly of components required. Figure 9 shows the final assembled mono block pump manufactured using FORTUS 900mc machine using ABS-M30i material.

6. RESULTS AND DISCUSSIONS

The case study product is manufactured using all three manufacturing approaches. In these processes, detailed time study, motion study and detailed manufacturing process and cost analysis are determined. Based on these data, Table 4 shows the results of all three approaches in terms of time, cost, initial investment, quality and performance.

Table 4: Comparison Study of Conventional Manufacturing, CAD/CAM Approach and AM Manufacturing

	Time (Hrs)	Cost (Rs)	Initial Investment (Rs)	Quality	Performance (%)	Work Space
Conventional manufacturing	8 days	3500	1.2 crores	Average	78	More
CAD/CAM approach	6 days	12000	1.5 crores	Good	92	Average
AM approach	1.5 days	32,000	1.5 crores	Above average	86	Best

7. CONCLUSIONS

A product such as mono block pump has several components. The conventional manufacturing and CAD/CAM approach manufacture each component one at a time. In this process, material is removed from the raw materials. Then each components are assembled together to form the finished product. The Additive manufacturing approach use to produce finished product in a single operation. In other words, the materials are added layer by layer to form the finished product.

From the Table 4, it is evident that all three manufacturing approaches help to manufacture mono block pumps. The conventional manufacturing approach takes not only longer time to product the product (poor product development process) but also produces average quality when compare to other two approaches. However, the cost of the finished product is less due to mass production model.

The CAD/CAM approach takes shorter time to produce the product (better product development process) when compared to conventional manufacturing approach, but it takes longer time to produce to the product when compared to AM approach. It is important to note the quality of the finished product (mono block pump) is better than other two approaches. However, the cost of the product is higher than conventional approach because of huge initial capital investment.

The additive manufacturing approach takes shorter time to produce the product (best product development process)

when compared to other two approaches. This is because the finished product is built as one piece (no assembly operations required). In addition, the quality of the finished product is better than the conventional manufacturing approach. However, the performance of the product is less than CAD/CAM approach because of restriction in material selection.

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